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DOI
10.4324/9780429029530-8

Publication date
2020

Document Version
Author accepted manuscript

Published in
Blockchain and Web 3.0

Citation for published version (APA):
Bodo, B., & Giannopoulou, A. (2020). The logics of technology decentralization - the case of distributed ledger technologies. In M. Ragnedda, & G. Destefanis (Eds.), *Blockchain and Web 3.0: Social, Economic, and Technological Challenges* (pp. 114-129). (Routledge Studies in Science, Technology and Society; Vol. 41). Routledge. https://doi.org/10.4324/9780429029530-8

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THE LOGICS OF TECHNOLOGY DECENTRALIZATION - THE CASE OF DISTRIBUTED LEDGER TECHNOLOGIES

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Amsterdam Law School Legal Studies Research Paper No. 2019-05

Institute for Information Law Research Paper No. 2019-02

Bodó, B., & Giannopoulou, A. (Accepted/In press). The logics of technology decentralization: the case of Distributed Ledger Technologies. In M. Ragnedda, & G. Destefanis (Eds.), *Blockchain and Web 3.0: Social, Economic, and Technological Challenges* Routledge.

The logics of technology decentralization - the case of Distributed Ledger Technologies

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Abstract

Decentralization is heralded as the most important technological design aspect of distributed ledger technologies (DLTs). In this chapter we'll analyze the concept of decentralization, with the goal to understand the social, legal, economic forces that produce more or less decentralized techno-social systems. We first give an overview of decentralization as a political ideology, and as an ideal and natural end-point in the development of digital technologies. We then move beyond this discourse and treat decentralization, its extent, its mode, the systems which it can refer to as the products of particular economic, political, social dynamics around and within these techno-social systems. We then point at the concrete forces that shape the actual degree of (de)centralization. Through this, we show that the extent to which a techno-social system is (de)centralized at any given moment should not be measured by its distance from an ideological ideal of total decentralization, but should be seen as the sum of all the social, economic, political, legal forces that impact a techno-social system.

I. Distributed ledger technologies and the ideology of decentralization

In the history of internet there seems to be a recurring hope that open source, decentralized, and distributed digital technologies would give rise to novel, revolutionary modes of social, political, economic organization, which build upon, and reflect the intrinsic characteristics of the underlying technology. Roughly twenty years after JP. Barlow's Declaration of the independence of cyberspace (Barlow, 1996), which heralded the birth of web 1.0, and ten years after Benkler's the wealth of networks (Benkler, 2006), which marked the mainstreaming of web 2.0, in 2016, blockchain technologies captured the imagination of a diverse group of social actors from crypto-anarchist software geeks, via investors, to governments. Their hope was, again, that technological decentralization would provide a solution to a wide range of problems that include the governance of global financial system, the excessive power of online platforms, or the way societies maintain property registries.

The term "Blockchain technologies", or Distributed Ledger Technologies (DLTs) describe a wide range of technological innovations which use advanced cryptographic techniques to create decentralized technological network infrastructures to facilitate social coordination among strangers without relying on existing institutions or traditional intermediaries. The coordination takes place via a shared database. The integrity of this database is guaranteed by an algorithmic consensus among the members of the network. The database has no limitations on what it contains: it can record time-stamped documents, transactions of unique tokens or software code that allows for the automatization of coordination. (Narayanan et al., 2016)

Blockchain technologies brought together long existing ideas in a new constellation (Narayanan & Clark, 2017), which created an opportunity to see this new technology as a point of discontinuity, a revolutionary moment, rather than a marginal advance in, for example, the science of cryptography or the design of peer-to-peer systems. Such moments of perceived discontinuity create uncertainties around the unexplored, unknown potentials of the technology, which, in the case of DLTs led to widespread and enthusiastic speculation about an imminent political, economic and social disruption. After two failures for the brave new, self-governed, autonomous world to emerge, there was again a widespread hope that on a decentralized and disintermediated technological basis technologically empowered individuals would create horizontal, just, meritocratic, self-governing communities, emancipated from the oppression of states, corporations and other traditional economic or political middlemen (Swan, 2015; Tapscott & Tapscott, 2016; Wright & de Filippi, 2015; Wright & de Filippi, 2018).

The term "decentralization" enjoys an almost mythical status in the discourses around DLTs in particular, and digital technologies in general. This is partly due to the original design of the internet architecture, which found an effective safeguard against a nuclear attack on a communication network by eliminating central points of failure or control. This has led to more metaphorical interpretations of the advantages of decentralized architectures in the form of John Gilmore's quote: *"The Net interprets censorship as damage and routes around it."* (Elmer-DeWitt, 1993) In 2006, Benkler stressed the relevance of decentralization in similar, albeit seemingly less loaded terms: *"[The] primary attribute [of centralization] is the separation of the locus of opportunities for action from the authority to choose the action that the agent will undertake. [...] 'Decentralization' describes conditions under which the actions of many agents cohere and are effective despite the fact that they do not rely on reducing the number of* *people whose will counts to direct effective action."* (Benkler, 2006, p. 62) In the context of DLTs, decentralization (and anonymity, not discussed here) provides immunity against laws: "*It's only through decentralization and anonymity that the system can remain free from outside influence, such as government regulation."* (Van Wirdum, 2015) "Policy neutrality" - as legal impunity is referred to by the same text - , is achieved because it's difficult and costly to coordinate enforcement against many, small, geographically dispersed, anonymous network constituents.

The normative discourse on decentralization

Decentralization in the technology discourse is rarely a descriptive category with its own particular costs and benefits, but rather a normative ideal. Centralization means the rule of the few over the many, the potential for censorship, for coercion. Decentralization is seen as the architectural guarantee of censorship resistance, and a safeguard against the coercive influence of any centralized, top-down force. The external forces of control --institutions, intermediaries, rules, laws, and norms-- prevent the ideal, purely technological modes of private ordering, based on the horizontal self-organization of equal peers. The social order that is expected to emerge on decentralized technologies is seen as inherently superior to what the status quo has to offer. The teaser of the Internet Archive's Decentralized Web Summit perfectly encapsulates this approach to the cascading social and political impact of technological decentralization: *"The Internet Archive's Decentralized Web Summit is dedicated to creating the web we want [and the web we deserve]. We are convening those who want to build a web that...Remembers. Forgets. That's safe. That cares about people. That's a marketplace. That's a public square. That learns. That's magical. That's fun. A web with many winners. A web that's locked open for good."*[1] Decentralization is a technological architecture that replaces existing modes of control and reverses their negative effects. It is a higher technological ideal to be strived for, a superior mode of technological design, a "*step forward in the evolution of systems*" ((Kelly, 2014) quoted in (Baldwin, 2018)), which could enable its users to effectively neutralize or counter the tyranny of states, the injustices of markets, and the untrustworthiness, corruptibility or outright corruption of various middlemen.

Looking at technological decentralization as an utopian ideal to strive for leaves little room for a more analytical approach. We agree with Baldwin, that the actual extent and mode of decentralization of complex techno-social assemblages are the products of concrete social, political and economic conditions "*based upon a geopolitical decision, being a contingent choice, serving a specific historical function, and with appropriate cost-analysis"* (2018, p. 3). In the next section we outline some of these forces which shape the degree of centralization of a techno-social system in different dimensions.

II. The logics and dimensions of decentralization

What are the relevant dimensions of decentralization?

[1] https://www.decentralizedweb.net/

Decentralization of a complex techno-social assemblage can be discussed in relation to both all the resources which are necessary for the production of the assemblage, and for all the domains the assemblage offers its products/services to. In the case of DLTs, they must secure inputs from a wide variety of markets: financial resources such as investment; human resources such as software development, or legal expertise; technical resources such as the capacities required to mine, or run a full node; or infrastructural resources such as access to specialized hardware, energy, network connectivity, or cloud services. Similarly, the concentration (centralization) of markets which use the services offered by or through a technology can also be considered: the number of users both human and institutional, and their concentration in various dimensions, such as legal/illicit uses, volume, geography; the number and distribution of holders of different rights related to the technology (such as ownership, management, extraction, exclusion, etc), and the distribution of costs, and of any rewards.

Decentralization, in the context of DLTs is usually discussed in terms of software decentralization, which according to Buterin (2017a) has much fewer dimensions: (1) Architectural ("How many physical computers is a system made up of? How many of those computers can it tolerate breaking down at any single time?"); (2) Political ("How many individuals or organizations ultimately control the computers that the system is made up of?"); and (3) Logical ("If you cut the system in half, including both providers and users, will both halves continue to fully operate as independent units?") According to this classification, "*Blockchains are politically decentralized (no one controls them) and architecturally decentralized (no infrastructural central point of failure) but they are logically centralized (there is one commonly agreed state and the system behaves like a single computer)*".(Buterin, 2017a) This classification is only little more than a thought experiment, but we quote it here because it comes from one of the most influential architects of the blockchain technology space. It is admittedly rough and debatable, and indeed, various studies that measured DLTs decentralization suggest a number of additional dimensions, the (de)centralization of which may have far-reaching impact on the political goals technical decentralization tries to achieve. It has been shown that the (de)centralization at the deep networking level, such as bandwidth, network latency, or fairness (Gencer et al. 2018), the control over the production of code (Azouvi, Maller and Meiklejohn, 2018), or various dimensions of users, such as marketplaces, or web wallets (Gervais et al., 2014; Srinivasan, 2017) all affect the degree of decentralization of DLTs. The studies also confirm that the decentralization of the different components of a complex techno-socal assemblage are not independent of each other. Their mutual interdependence creates a highly dynamic system subject to often unforeseen external forces.

The forces that produce (de)centralization

The history of the internet is also the history of the recentralization of networks which were initially designed to be decentralized. DLTs are no exception to this rule. In recent years we also witnessed the lack of decentralization, or substantial recentralization of DLTs in terms of, for example, mining power, at the layer of core code developers, or at major cryptocurrency exchanges (de Filippi & Loveluck, 2016). In response, a number of social, and technical innovations are being proposed. On-chain governance is supposed to submit the governance of the technology to the rules encoded in the technology, supposedly making it more transparent, accountable, and less arbitrary. Novel consensus mechanisms such as Ethereum's Casper[2] try to address the concentration of Proof-of-Work mining (Bonneau et al., 2015) and the cartelization of Proof-of-Stake approaches[3]. Specialized mining hardware (ASIC) resistant protocols are being proposed to address dynamics of recentralization at the levels of hardware. As these dynamics suggest, at any given time multiple, often interdependent forces shape the degree of centralization in often more than one layers of DLTs. In the following we'll discuss a number of such forces, that we were able to identify through the analysis of (1) discussions that take place in the generalized online fora, and in specialized venues; (2) white-papers that spell out the technical, economic, social, political visions of various blockchain projects. The items on this list roughly map onto Lessig's (1999) pathetic dot theory: markets, architecture, laws and norms, but they offer a more detailed, context specific insight into the actual workings into these forces. The list is far from being complete, and further work is needed to fully account for all the logics that produce (de)centralization in a techno-social system. Yet --we believe-- the most important of these forces are the following: (1) Ideology / systems design; (2) Internal control / governability; (3) External recognition; (4) External threats; and (5) Endogenous and exogenous economic incentives.

1. Ideology / systems design

While the quest for technological decentralization is often seen as a highly political endeavour, rooted in specific, techno-libertarian, or neo-liberal ideologies (Barbrook & Cameron, 1995; Chohan, 2017; Golumbia, 2016; May, 1994; Morozov, 2014), the foundational paper introducing Bitcoin (Nakamoto, 2008) does not directly invest in introducing an ideology of decentralization. However, an indirect reference exists in the Bitcoin genesis block, and in subsequent posts published by Nakamoto on the functioning of Bitcoin (Nakamoto, 2009). The message in the genesis block references an article in The Times newspaper on the proposed second bailout of commercial banks during the 2008 financial crisis. The Nakamoto paper describes a technology that can be applied without needing established, centralized, and trusted intermediaries. Focused on currencies, which are formed based upon the most centralized models, Satoshi explains that "*while the system works well enough for most transactions, it still suffers from the inherent weaknesses of the trust based model*". Nakamoto delivered a detailed roadmap on how to reverse this model.

The success of Bitcoin, as an incorruptible trustless system incited a renewed interest in decentralization as a technological solution to power inequalities, and inspired the generalization of the Bitcoin idea. The Ethereum white paper (Buterin, 2013) presented blockchain technology as an underlying infrastructure that could apply the impersonal disintermediarized trustless model proposed by the Nakamoto paper to "more than just money". Ethereum introduced decentralized applications (Dapps) and decentralized autonomous organisations (DAOs), all running on a peer-to-peer network instead of running on a centralized computer.

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[2] https://github.com/ethereum/wiki/wiki/Casper-Proof-of-Stake-compendium
[3] https://github.com/ethereum/wiki/wiki/Proof-of-Stake-FAQs

Yet, decentralized technologies are proven to be prone to occasional recentralization due to forces we discuss below. For example, some blockchain technology architects, like Zamfir (2016) are focusing their work on the direct and indirect incentives which may lead to the recentralization of power in decentralized blockchain networks. More specifically, the preferred method of establishing consensus on the blockchain has been a dividing issue among different projects. Miner competition in validating blocks is an essential part in decentralized blockchain projects. The recentralization (Gencer et al., 2018) of mining power proves to be not only a practical issue, but also a political one. Building technological resistance to centralization of miners has become an integral part of new cryptocurrencies, demonstrating their belief that decentralization on the consensus level and above is fundamental to the design of the DLTs. For example, the cryptocurrency Monero opted to change its consensus validating algorithm every six months to resist ASIC miner centralization. These technological choices ultimately correspond to the decentralization ideals of the techno-social assemblage, while also determine the internal power balance of the community, and the success of the project.

With the introduction of smart contracts, the logic of decentralization reached the level of blockchain governance itself. This was a development to be expected: despite all the ideological commitment to decentralize social processes through technology, DLT development remained heavily centralized in terms of software developers, and their governance mechanisms. The communities behind the code were, and many still are weakly organized; they tend to lack formal institutions, processes; they often operate in the state of anarchy, or under the rule of benevolent dictators; and in absence of more sophisticated conflict resolution mechanisms, they often have to resort to splitting (forking) the code and the networks to resolve their ideological, or systems design differences. Consequently, the governance of DLTs turned out to be of central importance (de Filippi & Loveluck, 2016). The question that in these contexts emerged was whether the production of DLTs can be governed using DLT technologies themselves: is it possible to govern, in a decentralized manner, on a decentralized technology, the production of that decentralized technology? In response, multiple efforts started to work on what is called the problem of “on-chain governance”. For example, the Tezos blockchain implements a decentralized modular governance model for smart contracts and decentralized applications that would permit for more coordinated “radically decentralized protocol forks” (Goodman 2014). Similarly, decentralized applications like Aragon[4] offer modular decentralized organisation models that can be used by companies developing their blockchain project or by decentralized autonomous organisations. These additional layers address the goal of decentralization by inserting mechanisms that would resist centralization tendencies on the governance and decision-making levels.

The efforts to implement automated, decentralized decision-making mechanisms for the governance of blockchain-based applications and organisation, have provoked a number of conflicts between ideas of decentralization and system design. As it will be shown later on, examples of these controversies can be found on the block-size debate for Bitcoin, the Tezos foundation lawsuits and the Ethereum DAO hack

[4] According to the project’s white paper, “the Aragon Network provides a subjective governance layer that improves the overall usability of Ethereum by providing a mechanism for pseudo-anonymous blockchain entities, including decentralized autonomous organizations (DAOs) and individuals, to create flexible human-readable agreements that are enforceable on-chain”. Retrieved from https://github.com/aragon/whitepaper

(DuPont, 2017). The ideology-driven decentralization maximalist approach could only be realized at the expense of other important values, such as technical efficiency, governability, or social recognition and diffusion. Take, for example, the now infamous and still ongoing block-size debate. The issue in that controversy is the implication of increasing the size of the blocks on the Bitcoin blockchain. On the one hand, bigger blocks would increase the throughput of the system, allowing for more transactions per minute to be processed, and a potentially higher level of recognition of the cryptocurrency as a payment system. Opponents to the increase, however, pointed out that larger blocks means that individuals with less computing resources and on slower networks are discouraged to participate in the mining process, while big mining consortia would enjoy a number of self-reinforcing advantages (van Wirdum, 2015). A larger block size may help the network to scale up, but it threatens with the recentralization of the network. This dilemma has caused divisions and the ultimate schism in the Bitcoin community (de Filippi & Loveluck, 2016). Many members adhering to the "true spirit" of decentralization according to Satoshi's vision protected the cap for ideological reasons. Others disagreed, and decided to create and sustain a forked alternative version of the Bitcoin blockchain that is still maintained as an independent cryptocurrency. The disagreement has demonstrated that non-architectural choices have important consequences on the decentralized nature, and the development path of the technology.

2. Internal control and governability

One of the biggest challenges a decentralized system faces is its continuous maintenance and community governance. Every additional measure of decentralization to minimize external control also diminishes the control powers of the creators of the system. The decision-making processes that are are required by the maintenance of a control-proof decentralized system cannot be fully automated away. The elimination of single points of control makes the maintenance of the system slow, and the social coordination of the participating members cumbersome. It proved to be harder than expected to implement in practice the "governing without a government" vision of Satoshi. The Nakamoto consensus, as a technical approach to create a self-governing system is only useful to maintain a distributed nature of the ledger, but is unable to operate on other levels where decentralization may be desirable. The technology that allows avoiding reliance on external intermediaries was not sufficient to guarantee the decentralized nature of the technology when it came to core developers, full nodes, or miners, and other interests and stakes in the techno-social system.

Take for example, the current governance of the Bitcoin technology. Lacking a formal governance structure, the Bitcoin community coordinates ideas for improvements through the Bitcoin Improvement Proposals (BIP) system. It consists of a transparent process very similar to the code review process available on open source and free software projects (de Fillipi & Loveluck, 2016). Everyone can review the code and documentation and can make suggestions to modify and improve the system. However, the implementations of the code come from the team of core developers who take the decisions "on behalf of the community" and after the proposed BIP has an ultimate consent from "the consensus of the Bitcoin users"[5]. From a technical point of view, this (re)centralization tendency around the core developer team makes sense by virtue of their technical skills and very frequent involvement with the code.

The veto powers of the other members of the community act as a counterbalance to the power of the developer oligarchy. The blockchain core developers' protocol decisions have to be approved of and implemented by miners and other nodes. In case they disagree with the changes, they could also take the decision to fork the whole chain. Compared to miners and full nodes plain users have less veto power, but they still do possess some level of control, by for example not assigning market value to the tokens issued by the network.

One can argue that these built-in control mechanisms, and the possibility that actors can freely choose between competing chains and implementations, stabilizes, and potentially counteracts recentralization tendencies. Yet, only in a decentralized network such an indirect voting mechanism produces an effective democratic, horizontal self-governance of equals. In case of recentralization, there is a chance that this system of decentralized approval/rejection degenerates into a competition of highly centralized powers and leads to a potential tragedy of the anti-commons (Heller, 1998). This is exactly what is at stake with the current levels of concentration of mining power in the Bitcoin network. A small group of miners control more than 51% of mining power in the network, so it is relatively cheap and easy for them to prevent any changes in the protocol that might hurt their interests through coordination and collusion. Under such conditions the built-in informal governance mechanisms in the Bitcoin network were unable to handle the block size disagreement, which could only be solved by the forking of the codebase and the network.

The ability to maintain different versions (forks) of the blockchain, and users' freedom to decide which version to embrace can also be read as the expression of technical decentralization. On the other hand, while nothing prevents already centralized miners to produce the code, it is difficult for a small and dispersed group of coders to produce sufficient amounts of capital-intensive mining power. This means that it is very likely, that the current separation of code production and mining will consolidate under the miners, removing another layer of checks and balances which currently add to the decentralized nature of the system.

3. External recognition

While as it was stated earlier, the purported examples of Bitcoin and foundational blockchains like Ethereum are motivated by the goal of achieving "policy neutrality", the need to build compatibilities with existing systems creates a tendency to recentralize. If blockchain based systems and applications have to, or want to interface with existing institutions, practices, networks, because there is no other way to achieve their stated goals, the mere existence of this interface creates strong external and

[5] https://github.com/Bitcoin/bips/blob/master/README.mediawiki

internal incentives for legal compliance, and a corresponding "drift towards legality". This drift implies that the legal, political, economic systems and institutions develop the necessary tools to adopt the decentralized system. In a similar vein, DLTs also have to build the capacities to be recognizable by existing formal institutions, legal systems. Since legal compliance rests on parties being clearly identifiable, and rights and obligations being well defined, this drift towards legality further creates pathways of recentralization. Control of the blockchain through identifiable actors and processes translates into control of the code, of the network, and/or of the decision-making process.

From a legal perspective, the most prominent challenge for wide adoption stems from the need of identifying legal structures under which the constituents of a blockchain project can be recognized. The consequences of such a choice can be found in the identification of formal liable actors, in the regulation of the product and finally, in the wider adoption from society. The case of the Tezos Foundation demonstrates the high stakes around the external recognition of DLTs, the interplay between the external and internal status of a blockchain system, and interdependence of the external governance of a techno-social and the self-governance of the system which project is promising to build (Lewis-Kraus, 2018). The Tezos Foundation was established as a Swiss Foundation in Zug, Switzerland. A foundation under Swiss jurisdiction is a popular choice for some emerging blockchain projects, as it allows DLT developers to escape the regulations of the Securities and Exchange Commission in the U.S. or similar regulatory bodies in other countries. However, being a Swiss foundation showed its limitations, when the the collapse of trust among board directors of the Tezos Foundation locked up the the funds raised during the ICO. Due to regulatory governance and compliance issues Tezos has yet to launch its promised network to this date, and it is named in numerous class action lawsuits for investor fraud and securities law violations.

On a technological governance level, the irregular nature of code contributions and technological updates among core developers and community contributors appears as to inhibit the wider adoption of DLTs in more formal economic and governance contexts. The assumption that the semi-formal technical governance of the software code of DLTs will suffice to permit its integration with governmental and corporate institutions is incompatible with the reality of how institutions, especially in the financial sector implement technology. In these settings trusted intermediaries emerge in order to formalize the technical processes and to create liable actors or procedural guarantees. For example, efforts to formalize code production through standardization and the adoption of ISO certifications to DLTs heavily centralizes / (re)intermediates the technological stack via the validation process by external actors. A priori, *de facto* and *de jure* standardization of blockchain technology can facilitate the integration to existing trading and economic systems.

These (partial) recentralization processes do not necessarily mean that DLTs have failed their purported self-governing idealistic goals. Recentralization could create the conditions for wider adoption by formal corporate and government structures. Ultimately, the value of decentralization is measured against the value that will be derived from the wider adoption due to embrace and approval of institutional actors. In any case, such approval requires that part of the decentralization ideal is sacrificed for a more sophisticated governance that includes more robust regimes built for conflict resolution, technological auditing or risk management. For example, code vulnerabilities discovered on the Bitcoin blockchain illustrate the need for reinforcing code review processes. Similarly, the validation of the longest chain is still the only available predominant conflict resolution mechanism. It becomes thus evident that, for the moment, the safeguards created are still in an early stage and since they already demonstrate their shortcomings, there is ample room for improving the overall decentralized governance structure.

4. External existential threats

If we look at the history of the internet, of the open source software domain, of privacy enhancing technologies (PETs), or of file sharing networks, existential threats emerge to be the most effective drivers of technological decentralization. Such threats present a clear and present danger to the practices, freedoms, autonomy, or mere existence of technology enabled communities and practices. The network topology and the protocols of the internet were shaped by military concerns over the vulnerabilities of centralized communication networks, and the direct threat of a nuclear war. The open source software movement was galvanized by the enclosure of software due to the copyrightability of software code, and led to the decentralization of the loci of software development, the political decentralization of competing software implementations, and the legal decentralization through FLOSS licences. The Tor Onion Network is a decentralized network which provides anonymous communication to its users (Syverson, Dingledine, & Mathewson, 2004). Its development is partly funded by the US state intelligence services to obfuscate law enforcement and intelligence communications. File sharing technologies, from Napster to the bittorrent protocol became decentralized step by step, as lawsuits identified points where rights holders could shut down networks. (Bodó, 2011; Giblin, 2011)

External threats do not produce absolute technological decentralization. The exact degree of decentralization is set by the marginal costs and benefits of the attack and the defense. The bittorrent protocol decentralized p2p file sharing to the extent at which the extra costs associated with online copyright enforcement exceed the achievable extra benefits. The TOR network does not provide full anonymity, only renders monitoring and deanonymization prohibitively costly for anyone except probably state actors. Blockchain networks are not immutable, but a 51% attack is usually more costly than any potential benefits it can provide. Such decentralization is thus very pragmatic. While it responds to legal, political, or economic threats, is is also based on more or less precise cost-benefit estimates, and tends to not spend more resources on decentralization than what is absolutely made necessary by the economic, technological, political conditions of the external threat. In blockchain-based systems, this cost benefit analysis is also modelled in advance, and used to incentivize the production of the network. Such decentralization is also gradual and responsive, and develops in sync with the expected changes in the nature and the shifting economics of external threats.

5. Endogenous and exogenous economic incentives

The development of crypto-economics is one of the major, possibly long term contributions of the blockchain domain to science. It refers to the use of game theory to design economic incentive systems to encourage certain desired properties in techno-social systems to hold into the future, and discourage others to emerge (Buterin, 2017b), or a "*formal discipline that studies protocols that govern the production, distribution, and consumption of goods and services in a decentralized digital economy. Cryptoeconomics is a practical science that focuses on the design and characterization of these protocols.*" (Zamfir, 2015)

When Benkler formulated its commons-based peer production (CBPP) paradigm, his central concern was how to organize the production of a common resource pool through non-market incentives. The CBPP literature focuses on the intrinsic and social sources of motivation to explain the production of shared resources, and warns that extrinsic, monetary incentives actually crowd out other forms of motivations (Benkler, 2006, 92-99). In contrast, blockchain based crypto-economic techno-social systems differ from the logic of peer production in that they have built-in remuneration logics in the form of crypto-assets, or native tokens, which are used to incentivize the production of the resources the networks needs for its operation. Tokens are also used to compensate for the costs that such production activity incur (in forms of energy costs, investment, expertise) (Narayanan et al. , 2016) The token-based economic systems in DLTs are thus vehicles to extract and redistribute value. They are also designed in a way to only allow value extraction in certain, limited ways, which preferably prevent the reconcentration in various dimensions, such as value extraction power.

The blockchain technology community has paid a great deal of attention to the crypto-economic consequences of architectural choices, i.e how the incentive structures of stakeholders, and the corresponding Nash-equilibria of the games they are locked in may change due to different, on the surface purely technical decisions. The aforementioned Bitcoin block size debate is the obvious case to demonstrate how the game-theoretical consequences were having an effect on the application of a technological, architectural choice. Yet, not all such consequences can be modelled at the time of taking a technical decision, which leads to situations where exogenous economic incentives (those that weren't taken into account in the design) produce recentralization, and the endogenous incentives (those that are built in the system) are unable to prevent this, or in the worst case, they (unintendedly) aggravate the problem.

As Braudel (1992) and on his footsteps, deLanda (1996) warn us, market players have an inherent incentive to eliminate market competition, and the rules that control and ensure such competition. Blockchain based techno-social systems are no exception to this rule. Apparently, different blockchain stakeholders find ways through which they can eliminate competition from the provision of services the network relies on, resulting in the recentralization of decentralized systems. This antimarket, centralizing behavior can take multiple forms. Changing the endogenous incentive structures through majority vote, or if that fails, through a hard fork is one approach. The block size debate played out exactly this manner, and as the improvement protocols aiming to increase the block size were voted down (Andresen, 2015) a number of hard forks ensued. Alternatives like Bitcoin Cash, Bitcoin XT, Bitcoin Classic and Bitcoin Unlimited allow for a higher degree of potential centralization in exchange for higher capacity. On the other hand, exploiting exogenous economic factors can also lead to recentralization. To illustrate this point consider the dynamics of recentralization of the Bitcoin network. The specific algorithm used by Bitcoin's Proof of Work (PoW) encouraged the development of highly efficient, specialized mining hardware components (Dev, 2014), a market which turned out to be highly centralized. In a different layer, PoW mining turned out to be energy intensive, as both the running and the cooling of mining hardware requires substantial amounts of energy. Consequently miners tend to geographically cluster around cheap sources of energy, and cooler climates. For any given block, only one miner can claim the mining reward, which produces a very unpredictable revenue flow for each individual miner. In response miners organized themselves into a very small number of extremely influential mining pools which share mining revenues across members in a more predictable fashion.

Some of these centralizing economic incentives can be foreseen, and mitigated on the technology layer. Ethereum technology developers realized quite soon that market concentration through cartel formation is an issue to be dealt with on the level of the consensus protocol: *”Cryptocurrency is incredibly concentrated. So is mining power. Oligopolistic competition is the norm in many “real-life” markets. Coordination between a small number of relatively wealthy validators is much easier than coordination between a large number of relatively poor validators. Cartels formation is completely expected, in our context.[…] Blockchain architecture is mechanism design for oligopolistic markets.”* (Zamfir, 2016) Yet, such solutions are rarely straightforward, and there is no guarantee that the protocol design correctly predicts all potential exogenous incentives to recentralize.

III. Conclusion

At the moment there is a wide gap between the forms and extent of decentralization as prescribed by the ideology, and the practical forms in which it manifests in various blockchain networks. Different blockchain implementations serve as case studies in unexpected recentralization of a technological infrastructure designed to be decentralized out of pure ideological reasons. Focusing on decentralization as an end-goal, or as an ideologically supreme design choice *”conceals relations and systems of domination, exploitation, and alienation.”* (Baldwin, 2018, p. 6) In addition, looking at decentralization at the technical layer alone is hardly enough. As countless studies on technological communities clustered around decentralized technological infrastructures suggest, a decentralized technical architecture does not automatically produce decentralized governance structures, or more just worlds in general.

As we have seen with blockchain technology evangelists, and the web3.0 summit organizers, ideological commitment to decentralization may produce decentralization, but it is hardly the only one, and by all accounts, may not even be the most effective driver. Decentralization comes with severe trade-offs in terms of scalability, efficiency, usability, security, etc. The optimal choice in these trade-offs differs context by context, and there is hardly a one-size-fits all degree of decentralization in the many interdependent layers of a techno-social system (Wang et al., 2017).

Decentralization is a powerful architectural feature of digital technology, because it can raise the costs of enforcing legal rules, rights and obligations for private parties and the state alike. Unlike others (Wright and de Filippi, 2018), we are not convinced that decentralized blockchain networks would be able to bypass or negate the rule of law (Quintais, Bodo, Giannopoulou, and Ferrari, 2019), and would lead to the replacement of law by code. But different technological designs have different enforcement calculus attached to them. More decentralized technologies, if done right, can be more difficult to reign in. What we have tried to argue in this chapter was that it is important, for lawyers, policymakers, as well as those closely involved in the development, monetization, or use of the technology to understand how the regulation capacities of technological systems interact with, reinforce, contest, complement the regulatory capacity of legal instruments. Technology and law tends to develop in tandem: law develops to address new practices enabled by new forms of technology, and technology development reflects legal developments. This interlocking co-evolution of law and code has sometimes been referred to as an arms race, or whack-a-mole game, describing, for example the relationship of copyrights and file sharing technologies. However, such an approach locks technology and law in a binary opposition, a mutually antagonistic struggle for supremacy, sovereignty, revolt, and evasion. While this is a plausible scenario, it is not the only one. The concept, the process, the practical outcome of technology decentralization is more complex than what the code vs. law approach offers, and it is definitely not only about technological sovereignty, and legal impunity. As we have shown, the decentralization efforts, so central in the blockchain discourse, enable a wide variety of technology development trajectories, which produce different configurations of how law *and* code could work together to order technology-enabled practices and processes. In that process some outcomes pose less of a challenge than others. The file-sharing technology development ultimately produced a situation when law enforcement is only possible at the deepest infrastructural levels, at the wires controlled by legally not liable ISPs. The understandable resistance to such a drastic approach created a situation where a decentralized technology enables sustained infringing activity. The emergence of a similar outcome in the blockchain space is both possible, and avoidable through the better understanding of the processes that drive technology development.

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